solar cells from Royal Dutch Shell

new plant in Germany is most up-to-date in the world

Solar energy for the Gelsenkirchen plant: solar modules fitted to some 420 square metres of roof and frontage areas produce some 100,000 kWh of energy per year. The modules use semi-transparent Optisol™ photovoltaic cells from Pilkington Solar International.

With advanced automation and a planned output per production line of over 1000 cells per hour, the recently opened Royal Dutch Shell Group's new world-scale solar cell factory in Gelsenkirchen, Germany, close to the Dutch/German border sets new standards for the production of multi-crystalline silicon solar cells. The continuing acceleration of production and sales worldwide of solar cells is reducing the cost of solar-cell produced electricity by 6% annually, which must be good news for consumers.

By Ernst Krempelsauer

INTRODUCTION

The Royal Dutch Shell Group's interest in the solar electricity (also called photovoltaic) industry began in the early 1970s. The business grew with the establishment of Showa Solar KK in Japan and Shell Solar Energy BV. Until the opening of the Gelsenkirchen factory, Shell Solar Energy BV in the south-eastern Netherlands was the centre of the company's cell and module production.

The Shell Group's commitment to solar energy was reinforced in 1998 when the Group founded its fifth core business, Shell International Renewables, of which Solar is one of the three business units.

The decision of the Shell Group to build their new solar cell factory in Germany is based partly on the fact that Germany is currently the largest European market for solar cells and, perhaps more importantly, that the regional (Nord Rhein Westphalia) and national governments undertook to pay about 25 per cent of the cost of the factory. There is further support from the regional government for the associated Photovoltaic Information Centre. Yet another factor is that there is already a solar-cell manufacturing outfit in Gelsenkirchen: that of Pilkington Solar International. Finally, scientific support in Gelsen-kirchen comes from a branch of the Fraunhofer Institute for Solar Energy Systems. There is also the likelihood that Bayer Solar will start producing multi-crystalline wafers, the basis of solar cells, in Gelsenkirchen.

THE NEW FACTORY

Apart from its outstanding architectural design, the factory is noteworthy for its drastic shortening of the production line to only 70 metres (200 ft) and the complete automation of this with numerous newly developed production units. The plant consists of an hexagonal building with sloping roofs, in which production takes place at two levels, as well as a multi-storey, oval administration block with an annexed visitor centre. Most of the complex, which is 83 m long, 47 m wide, and 12 m high, is fitted with solar cells that produce 100,000 kW of energy per year. This means that the solar cells will be produced with the aid of solar energy.

Initially, the plant will use a single production line capable of manufacturing up to 5 million solar cells per year. This output can produce up to 10 MW of energy. Plans have already been approved to extend the plant to provide two more production lines to increase the overall annual output to 13 million solar cells capable of providing 25 MW of energy. These plans also include contingencies to cater for newly developed techniques.

THE MARKETS

The Shell Group believes that solar energy will play an increasingly significant role in meeting the growing energy needs of the world and that there are a wealth of applications for this environmentally sound and affordable energy solution.

A large part of the output of the new Gelsenkirchen plant will, of course, be exported. The Shell Group is particularly interested in rural electrification that brings decentralized renewable power to remote or non-grid supplied communities. Examples are 50,000 solar home systems for South Africa (in a joint venture with Eskom, South Africa's largest power company), and 100,000 for China. There is, of course, also a vast market in the industrialized world, USA, Europe, and Japan, for grid-connected solar systems. In these countries, there is also a market for stand-alone solar power supplies in remote locations, such as telecommunication sites.

AND COSTS?

Solar cells are expensive; at their current price they cannot possibly compete with traditionally generated electricty (fossil and nuclear). For instance, in Germany, the price of solar energy is about 53p per kWh (in Britain, the daytime tariff of traditionally produced electricity is 6.76p and the night-time tariff 3.28p per kWh).The production costs of photovoltaic modules are, however, falling and this trend seems likely to continue. The Shell prognosis is for a 6% cost reduction per year. This means that solar energy technology will become incresingly competitive when compared to fossil fuel or nuclear power stations.

The cost of photovoltaic panels can be reduced further, first by advanced automation in manufacturing and improved light conversion efficiency in current crystalline silicon technology. It could be followed by large-scale deployment of one of several types of thin film technologies. If these assumptions are correct, the price of solar energy and traditionally generated electricity will equate by around 2020.

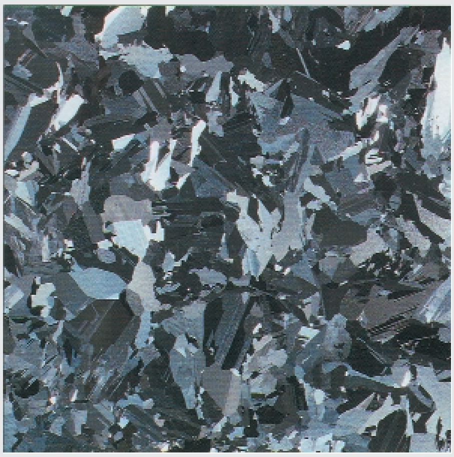
Greenpeace have also provided an interesting response to Shell's solar cell engagement. Shell and Greenpeace recently clashed vehemently on the Brent Spar incident. Although Greenpeace in principle welcomes the new solar cell plant, it criticises the invest-

From silicon wafers to solar cells

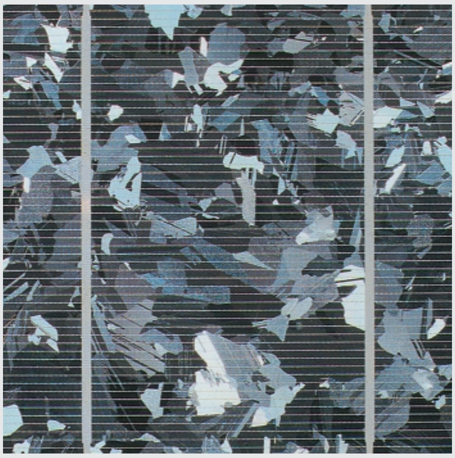
In the Gelsenkirchen plant, solar cells are manufactured from 12.5 cm square, 350 µm thick multi-crystalline silicon wafers. Silicon is one of the most abundant materials on the planet (in the form of quartz sand) and is an environmentally friendly material.

The wafer must first be smoothed and cleaned, that is, etched, thoroughly before it can be used to make a solar cell.

Next, one side of the wafer is made the equivalent of the positive terminal on a battery. This is done by applying a liquid containing phosphorous onto one surface in a process called doping.



Multi-crystalline silicon wafer



Metallized solar cell

The wafer is then heated in an oven to allow the phosphorous to eat its way into the surface of the silicon in a process called diffusion.

The next stage is the printing of electrical contacts on the front surface of the wafer. The contacts are made of a metal that collects and conducts electrons that are generated when sunlight strikes the cell. Obviously, the whole surface cannot be covered with metal, and the contacts therefore consist of a grid of 90 µm wide lines printed onto the wafer.

The wafer is then coated with an anti-reflective film of titanium dioxide (TiO_2) to ensure that as much light as possible is absorbed into the cell.

The cell is then turned over and the negative side of the solar battery is formed by coating the surface with a thin aluminium film in a process called metallization. The wafer is then heated again in an oven to ensure that the aluminium is fully absorbed into the silicon.

Finally, the positive and negative sides of the solar cell are isolated from each other.

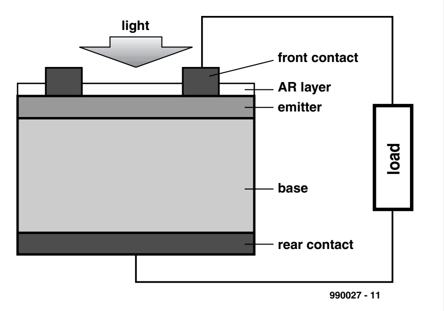
The technology of solar cells

Solar cells depend on the photovoltaic effect, a process in which two dissimilar materials in close contact act as an electric cell when struck by light or other radiant energy.

Light striking such crystals as silicon or germanium, in which electrons are usually not free to move from atom to atom within the crystal, provides the energy needed to free some electrons from their bound condition.

Basically, a solar cell consists of a large semiconductor diode with its p-n junction just under and parallel to the upper surface – see Illustration. The n (emitter) and p (base) regions are provided with ohmic contacts to enable an electric current to flow through an external circuit. The front contact is a grid that allows the loss-free flow of electric current but does not create a shadow on the active upper surface of the cell. An anti-reflection coating ensures that as much light as possible is absorbed into the cell. The back contact is flat.

The semiconductor material absorbs photons, the primary energy packets of light. The photons raise the energy level of the electrons in the semiconductor, exciting some to jump from the lower-energy valence band to the high-energy conduction band. The electrons in the conduction band and the holes they have left behind in the valence band are both mobile and can be induced to move. The electron motion and the movement of holes in the opposite direction constitute and electric current.



Construction of a solar cell

Solar cells based on silicon wafers

Currently, more than 80 per cent of solar cells produced worldwide use crystalline (c-Si) or multi-crystalline (mc-Si) silicon wafers. Power solar modules use these wafers exclusively. Solar cell technology is developing rapidly in the wake of microelectronics technology. Nevertheless, solar cells remain expensive and their efficiency is not high. However, there is a growing market need for them, which makes research into improving their performance/cost ratio essential and worthwhile. Laboratory models achieve efficiencies of up to 25 per cent (small-area modules) and up to 20 per cent(large-area modules). Commercially available cells have efficiencies of about 16% (c-Si) or 15% (mc-Si). These are confidently expected to improve to 18% and 20% respectively in the near future.

A relatively recent development is the crystalline silicon film solar cell. In this, a film 20–50 µm thick is deposited onto ceramic, graphite, or other materials. The advantage of this is a substantial saving of expensive silicon. Small-area laboratory models have achieved an efficiency of 11 per cent.

Solar cells based on gallium arsenide wafers

Gallium-arsenide (GaAs) solar cells have a higher efficiency than silicon-based types with a peak value of almost 26 per cent. However, their production costs are considerable higher than those of silicon types. Also, the cost of gallium-arsenide is much higher than that of silicon. Currently, GaAs solar cells are used almost exclusively in space technology. In future, they may well be used in concentrator systems.

A concentrator acts like a magnifying glass in focusing sunlight before it is absorbed by the solar cell. The power output of normal cells has been increased by up to 21 times by the ue of a concentrator. The highest efficiency has been recorded at around 34 per cent.

Thin film solar cells

Solar cells based on amorphous silicon

Solar cells based on amorphous silicon (a-Si) have no p-n junction but a p-i-n structure. In this structure, a region of almost intrinsic (i-type) semiconductor material is sandwiched between the p-type and n-type regions. The 1 µm thick depletion layer associated with a p-n junction is contained entirely within the i-region. The photo current is produced entirely in the depletion layer.

The cell is produced by depositing amorphous silicon onto glass at low temperature, which makes relatively low-cost, energy-efficient mass production possible. Unfortunately, this type of solar cell has an efficiency of only 7–8 per cent and it is, therefore, used only in low-power applications, such as pocket calculators and wrist watches.

Solar cells based on cadmium-tellurium

Cadmium-tellurium (CdTe) is a compound semiconductor that can be made only as a p-conductor. A p-n junction may be made by depositing a film of CdTe onto an n-conductor such as cadmium sulphide.(CdS). Laboratory models have achieved efficiencies of up to almost 16 per cent, but commercial CdTe modules have an efficiency of only 7–8%. Moreover, the use of cadmium in solar cells is a controversial subject.

Solar cells based on copper indium di-selenium

Copper indium di-selenium ($CuInSe_2$) is a compound semiconductor that can be made only as a p-conductor. A p-n junction may be made by vapour-depositing a film of CdTe onto an n-conductor such as cadmium sulphide (CdS) or zinc oxide (ZnO). Maximum efficiencies achieved under laboratory conditions are up to 18% (small area) and 14% (large area). Solar modules have an efficiency of up to 11%. The use of this material is also a controversial subject.

Solar cells based on dye-sensitized material

Solar cells based on dye-sensitized material belong to the category of photo-electro-chemical solar cells. In these cells, incident light is absorbed by a very thin (0.5–50 nm) dye film that is deposited onto a large, porous layer of rutile (TiO_2). When light is being absorbed, electrons of the dye material are excited, causing them to jump to the rutile. The current loop is closed by an electrolyte, which also provides regeneration of the dye molecules. This type of solar cell is simple and relatively inexpensive to produce. Prototype cells have an efficiency of up to 10%, but commercial models only 8%. Unfortunately, the stability of the cell cannot be guaranteed.

Source: Fraunhofer Institut für Solare Energiesysteme (ISE Freiburg), Dr. Dietmar Borchert

ment of a 'meagre' 50 million DM. The criticism is based on a report requested by Greenpeace from KPMG, the well-known Dutch auditors. According to the report, an investment of 629 million Euro would allow a solar cell plant with an annual output of 500 MW to be built, and the cost of solar-generated electricity to be reduced to 10p immediately, instead of after 20 years.

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